THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

JUNE, 1956

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

NICKEL

Panel Caving at Inco Canadian Mines

A. F. BROCK, R. J. McCORMICK and W. J. TAYLOR: 'Panel Caving at the Creighton Mine of The International Nickel Company of Canada, Ltd.'

Trans. Instn. Mining and Metallurgy, 1955-56, vol. 65, Pt. 2, pp. 37-53.

In the Creighton mine of The International Nickel Company of Canada 10,000 tons of ore are produced daily from the upper levels by a system of panel caving, while 4,000 tons of higher-grade ore are taken from square-set stopes in the lower levels. Present underground operations are conducted below the original open-cut, which is 200 ft. deep. Stoping of the breccia ore resulted in a pattern of subsidence below the open-cut that indicated the possibility of mining the lower-grade material left over the breccia ore by a cheap caving method. The present paper describes the research carried out to find the best method of doing this, and the success that attended the work. The lower-grade disseminated ore is now mined in this way: concentration is carried out at the mine, and concentrates are pumped directly to the reduction plant.

Electrolytic Polishing of Nickel

W. MACHU and A. RAGHEB: 'The Mechanism of the Electrolytic and Chemical Polishing of Metals, with Special Reference to Nickel.'

Zeitsch. f. Metallkunde, 1956, vol. 47, Mar., pp. 176-83.

The experiments reported were made with the aim of elucidating the significance of the passivating film which had been found to form during electrolytic polishing, and the effect of operating conditions on the degree of porosity of the film, believed by the authors to be of primary importance in understanding the mechanism of electrolytic and chemical polishing.

The anodes were of high-purity nickel sheet or cylinders, and platinum sheet was the cathode material. The polishing solutions employed were of two commercial types, the compositions of which are shown below:—

	%
(1) Sulphuric acid (sp. gr. 1·84) ..	33
Glycerin	33
Water	34
Operated at a current density of 11–22 amp./sq. dm.	
Temperature : 35°C. Time : 10 secs.	
(2) Phosphoric acid (sp. gr. 1·7) ..	60
Sulphuric acid (sp. gr. 1·84) ..	20
Water	20
Operated at a current density of 80 amp./sq. dm.	
Temperature : 60°C. Time : 5 mins.	

Since earlier studies had indicated the significance of current density, the effect of its variation, on time of passivity, was investigated, as was the effect of time of treatment and of the temperature of the solution.

Much detailed experimental information is given, the results of which are interpreted as follows:—

During the polishing process an oxide surface is formed on the nickel, and the porosity of this film is conditioned by the current density at which the polishing solution is operated. Failure to polish, and production of an etching effect on the nickel surface, is associated with an oxide film which is markedly porous: polishing is associated with a surface film of minimum porosity.

It is concluded that the very rapid removal of 'peaks' of surface roughness, during polishing, is due to the fact that the porosity of the oxide layer is greater at these positions than in the 'valleys'.

Nickel-containing Materials in Jewellery

K. H. MAIRS and J. M. WILLIAMS: 'The Rôle of Nickel and Nickel Substitutes in Jewellery Making.'

Corrosion, 1956, vol. 12, Mar., pp. 113t-18t.

The authors point out that nickel has become an important metal in the manufacture of low- and medium-priced jewellery and that experience during periods of shortage has served to emphasize its usefulness in this industry. Wrought low-carbon nickel is widely used in the production of gold-filled and rolled-gold plate, both as the base metal and as an interline: electrodeposited nickel is used as an undercoat on precious-metal-plated jewellery, and nickel is an important element in some precious-metal alloys, being employed as a hardening agent and, in certain types of white gold, as a means of colour control.

Restriction on the use of nickel during the war and post-war periods led to the employment of a number of substitute materials, with which, in some cases, far from satisfactory results were obtained. Corrosion was the main problem, and it was therefore decided to carry out a series of tests to determine the significance of nickel in jewellery and the properties which must characterize any materials which could be acceptable as substitutes for the various nickel-containing types normally used in that field.

Tests of corrosion-resistance, in simulated service conditions, were made by observing the open-circuit potentials developed between a typical 10-ct. gold alloy and various materials with which it might be paired. Each pair of materials was tested in two different electrolytes, representing, respectively, alkaline and acid perspiration: the compositions of the synthetic solutions are shown on p. 100.

Alkaline Solution

Sodium chloride	10 g.	dissolved in distilled water and diluted to 1 litre
Ammonium carbonate (USP)	4 g.	
Disodium ortho-phosphate..	1 g.	

Acid Solution

Sodium chloride	10 g.	dissolved in distilled water and diluted to 1 litre
Lactic acid	1 g.	
Disodium ortho-phosphate..	1 g.	

The solutions were prepared in accordance with A.S.T.M. Specification D627-49T: the same solutions are covered by Federal Specification CCC-T-191b (method 5682).

Each material was subjected to test in two physical conditions (annealed, and cold-rolled to 50 per cent. of the original thickness). The test cells were run at room temperature and recorded at 75°–80°F. (24°–27°C.). The types of material tested are shown below:—

24-ct. Gold (Au 99·95%min.).
10-ct. Yellow Gold (Au 41·67, Cu 38·5, Ag 5·83, Zn 12·83, Ni 1·17%).
Sterling Silver (Ag 92·5, Cu 7·5%).
800 Silver (Ag 80, Cu 20%).
Stainless Chromium-Iron.
Copper-gold alloy used as base for rolled-gold plate (Cu 92, Zn 7, Sn 1%).
10% Nickel silver (Cu 66·7, Ni 9·3, Pb 0·05 max., Fe 0·05 max., Mn 0·50 max. %, bal. Zn).
18% Nickel silver (Cu 65·4, Ni 18·7, Pb 0·10 max., Fe 0·25 max. %, bal. Zn).
Aluminium bronze (Cu 92, Al 8%).
Low-carbon Nickel (C 0·02% max.).
Type 305 Nickel-Chromium Stainless Steel (Cr 17-19, Ni 10-13, C 0·12 max. %).

Curves showing the behaviour of the respective materials are illustrated in the paper. From the observations made the following conclusions are drawn:—

'(1) The resistance of nickel to corrosion by synthetic perspirations is not completely satisfactory. In acid perspiration there can be marked general attack on this metal, but, fortunately, there is little tendency toward pitting or crevice corrosion. It is fortunate also that the normal products of corrosion are neither voluminous nor highly coloured. For these reasons it is possible for articles made of nickel to withstand considerable corrosion without harmful or objectionable results.

'(2) No single substitute material has been recognized that possesses the general usefulness of nickel for jewellery.

'(3) The nickel-chromium steel (Type 305) has excellent corrosion-resisting characteristics, but, because of the high annealing temperature required, it is not a suitable base for gold-clad materials. This material is very satisfactory for constructional purposes, and represents a highly economic method of employing nickel.

'(4) Under many conditions the chromium-iron is not sufficiently resistant to corrosion by perspiration to be of great value in jewellery, but it is possible that development of more satisfactory passivating treatments would widen its application.

'(5) The copper-base materials (including the nickel silvers) show generally poor resistance to perspiration: all such materials yield highly coloured corrosion products which are objectionable in use.

'(6) Silver-base alloys, especially sterling silver, show reasonably good resistance to perspiration, but they are considered to be unacceptable as substitutes for nickel in jewellery production, due to their lack of strength, hardness and wear-resistance, considerably higher cost, tendency to tarnish and corrode easily from agents other than perspiration, softness, and lack of compressive strength at the temperature involved in cladding.

'(7) Of all the materials tested, nickel has the best combination of properties for use as the base of rolled-gold plate.'

(The article is based in part on studies made for the New England Manufacturing Jewellers' and Silversmiths' Association, by the Engineering Experiment Station, University of Rhode Island, and the Metals and Controls Corporation of Attleboro, Massachusetts.)

Nickel and Nickel Alloys in Digital Computers

See abstract on p. 105.

Metallurgical Research in Relation to Nuclear-Power Plant

See abstract on p. 117.

Determination of Metallic Nickel in the Presence of Oxides

C. EK: 'Method of Determining Metallic Nickel in the Presence of Oxides of Nickel in Complex Materials (Ores).'

Analytica Chimica Acta, 1956, vol. 14, Apr., pp. 311–17.

During investigations on the behaviour of metallic nickel in $HgCl_2$-,KCN-, and HCl-containing media, it was noticed that in certain cases dissolution of nickel metal was achieved, while a mixture of nickel oxides remained absolutely unaltered.

The working conditions were studied and on the basis of the results obtained two methods have been developed for the determination of metallic nickel in the presence of nickel oxides in complex materials, including ores.

These procedures are described in detail, and the results of typical experiments are given. It is shown that an accuracy of about 5 per cent. can be obtained.

Co-Precipitation of Cobalt with Nickeldimethylglyoxime

G. K. SCHWEITZER and B. L. McDOWELL: 'Co-Precipitation of Cobalt with Nickeldimethylglyoxime.'

Analytica Chimica Acta, 1956, vol. 14, Feb., pp. 115–20.

The co-precipitation of cobalt with nickel precipitated as the dimethylglyoxime complex was investigated

in various conditions, in material containing small amounts of cobalt relative to the nickel present. Precipitations were carried out in ammonia and in acetate solutions, at 25° and 85°C., with slow and with rapid addition of the solution of the precipitating agent: the influence of various digestion times was also studied. In each experiment the amount of cobalt was 612μg and the amount of nickel was 57·6 mg.

Of the methods investigated, minimum co-precipitation was achieved by slow addition of ammonia to the acid nickel, cobalt and dimethylglyoxime solution, followed by a 30-minute digestion, all the processes being carried out at 25°C.

Use of Manganous Salts in E.D.T.A. Titrations: Determination of Nickel

J. KINNUNEN and B. WENNERSTRAND: 'Improvement of End-Point in E.D.T.A. Titrations through Use of Manganous Salts.'

Chemist-Analyst, 1955, vol. 44, June, pp. 33–4.

The very sharp end-point obtained in titration of manganous ions with ethylenediaminetetraacetic acid (E.D.T.A.) led to investigation of utilization of this end-point in titration of other metals. The general procedure developed by the authors consists in adding an excess of standard E.D.T.A. solution to the sample, and back-titrating with a standard solution of a manganous salt. Details are given of reagents required and of procedure for determination of copper, nickel, iron, cobalt, vanadium and chromium in solution. Sharply defined end-points are obtained with Erichrome Black T indicator. Typical determinations described include estimation of nickel in nickel-sulphate solutions, and in nickel-dimethylglyoxime precipitate.

Use of Chelating Agents in Determination of Nickel

B. D. BRUMMET and R. M. HOLLWEG: 'Chelating Agents in Non-aqueous Titrimetry.'

Analytical Chemistry, 1956, vol. 28, Apr., Pt. I, pp. 448–50.

The authors describe a non-aqueous titrimetric procedure, using chelating agents for determining metal ions. The procedure has been applied to estimation of nickel, cobalt and copper, and has been found to give accuracy and precision comparable with that obtainable with a strong acid-strong base titration. Details are given of the use of the method on nickel-chloride, cobalt-chloride and copper-chloride solutions. In the determinations on nickel, 8-quinolinol, dimethylglyoxime and dithizone were employed as the chelating agents.

'PAN' as Indicator in Determination of Nickel

H. FLASCHKA and H. ABDINE: 'Complexometric Micro-titrations using PAN as Indicator.'

Chemist-Analyst, 1956, vol. 45, Mar., pp. 2–3.

The authors review earlier literature relating to the use of the compound 1-(2-pyridyl-azo)-2-naphthol (PAN) as indicator in complexometric titration of copper, zinc and indium, and describe procedure for determining iron, nickel, cobalt, cadmium and other metals by means of PAN, used in conjunction with ethylenediaminetetraacetate (E.D.T.A.).

Polarographic Determination of Nickel in Copper Alloys

D. J. FERRETT and G. W. C. MILNER: 'Analytical Applications of the Baker Square-Wave Polarograph. Part II: The Analysis of Copper-base Alloys and Steels.'

Analyst, 1956, vol. 81, Apr., pp. 193–203.

It was shown in Part I of this investigation that the derivative nature of the square-wave polarograph permits determination of mixtures of elements which, when conventional polarographic technique is employed, give mutually interfering steps. In Part II the value of the square-wave polarograph is demonstrated by reference to its use in the determination of zinc and of nickel in copper-base alloys, and in the determination of copper, lead, tin and chromium in steels.

Determination of Nickel in Effluents

ASSOCN. BRIT. CHEMICAL MANUFACTURERS AND SOC. ANALYTICAL CHEMISTS: 'Recommended Methods for the Analysis of Trade Effluents. Methods for the Determination of Iron, Mercury and Nickel.'

Analyst, 1956, vol. 81, Mar., pp. 176–80.

Iron: After destruction of the organic matter, iron is determined colorimetrically as the purple thioglycollate.

Mercury: After destruction of organic matter by a special nitric acid-permanganate treatment under slight pressure, iron is first suppressed by hydroxylamine, and the solution is made acid to eliminate other heavy metals; the mercury is then extracted with toluene as the golden-brown dithizonate, which is determined colorimetrically.

Nickel: After destruction of the organic matter, nickel is extracted from the ammoniacal solution as its dimethylglyoxime complex, and is finally determined as the nickelic complex. The procedure is generally applicable, for nickel contents up to 100 mg.

Full details of procedure are given for estimation of each element.

Determination of Magnesium and of Manganese in Nickel

W. NODDACK, G. ECKERT and K. RIEDEL: 'Analysis of Nickel Alloys for Oxide Cathodes. I. Determination of Magnesium.'

Zeitsch. f. analytische Chemie, 1955, vol. 147, pp. 417–26.

G. ECKERT: 'II. Determination of Manganese', *ibid.*, vol. 148, pp. 14–20.

Details of methods developed for estimation of these two elements in nickel alloys used in electronic valves. Particulars of the main features of the respective procedures are given in *Chemical Abstracts*, 1956, vol. 50, Feb. 25, pp. 2358–9.

Colours Produced in Glass by Nickel

H. MOORE and H. WINKELMANN: 'The Colours of Nickel in Glasses of Various Types and their Implications concerning Glass Structure. Part I. The Types of Absorption Spectra given by Nickel in Glass.' *Jnl. Soc. Glass Technology*, 1955, vol. 39, Oct., pp. 215T–49T.

'Part II. Detailed Study of the Absorption Curves given by Nickel in Glasses and Certain Sintered Masses', *ibid.*, pp. 250T–86T.

'Part III. Studies of the Absorption Spectra of Nickel in Various Solutions and in Certain Organic Compounds, also of the Magnetic Properties of Nickel in the Various Experimental Glasses, in Relation to the State of Nickel in the Different Glasses', *ibid.*, pp. 287T–313T.

Glasses containing colouring oxides usually show colours closely resembling those characteristic of aqueous solutions of salts of the corresponding metals. The colours given by nickel in glass are, however, markedly different from those of nickel oxide, nickel salts and solutions of nickel salts. For example, most nickel salts are green, whereas soda-lime-silica glasses of ordinary composition are coloured brown by nickel, and potash-lime-silica glasses containing nickel are blue or blue-purple, as are nickel-containing potash-lead-silica glasses.

Up to the present no explanation has been found for these anomalies, and the object of the comprehensive investigation now reported was to study the ultra-violet and infra-red absorptions of glasses containing nickel, and their absorptions in the visible spectrum, and, if possible, to correlate these data with the absorptions of nickel salts and of organic compounds containing nickel.

Part I. In the experimental work described in Part I a study was made of the colours given by nickel in binary alkali-silica glasses and ternary glasses of the soda-lime-silica type, in borates and borosilicate glasses, and also in non-silica, non-alkali glasses consisting of CaO, B_2O_3 and Al_2O_3, which are known as 'Cabal' glasses. The transmission curves of the resulting glasses were obtained over the wavelength range from about 300 to 2300 μ. It was found that the curves obtained could be divided into three types, characterized by the presence or absence of six main absorption bands, which are referred to in the paper as bands 1–6.

The 'Cabal' glasses give the simplest type of curve, with only three absorption bands, Nos. 1, 5 and 6, and are of a brown colour. Borates and borosilicates containing alkali less than some fairly definite proportion have four absorption bands, Nos. 1, 3, 5 and 6, and the visual colour is green. Binary alkali silicates and ternary silicates of the alkali-lime-silica type give absorptions corresponding with bands 1, 2, 4, 5 and 6. The visual colours of the silicate glasses depend on the relative intensities of bands 1 and 2, and on their precise positions in the spectrum. For example, soda glasses are brown to the eye and potash glasses are blue or blue-violet, though their absorptions are of closely corresponding types. For convenience, the three types of transmission are referred to as of the 'brown', 'green' and 'undulatory' forms; they indicate that nickel can exist in three different states in glass, corresponding with different configurations which depend on the composition of the glass and on the structure imposed by the composition.

Part II reports a more detailed study of the absorptions of the glasses described in Part I: the three types of absorption spectra confirm that nickel can exist in three different states in glass.

It was found that even in base glasses of identical composition, absorptions were not proportional to concentration of nickel. In considering the curves, attention was therefore given to the positions and intensities of the centres of the various absorption bands and their relation to variation in composition of the glass. This part of the paper also includes data on sintered masses of other types.

Part III of the report deals with further tests made to ascertain the states in which nickel can exist in glass. The absorption spectra of solutions of nickel salts and of some complex nickel compounds were studied, together with the magnetic properties of the nickel in various experimental glasses.

The conclusions drawn from the observations made throughout the whole investigation are summarized by the authors as follows:—

'Nickel as a divalent ion in the simplest possible co-ordination with oxygen gives the 'brown' type of transmission curve; this would correspond with the Ni^{2+} ion occupying a position between two O^- ions single-bonded to structure-building units, i.e., in a 'bridging' position between structure-building units.

'Nickel as a divalent ion in 6-fold co-ordination within the interstices of the glass structure gives the 'green' type of curve.

'The 'undulatory' form of curve is attributed to nickel as a divalent ion associated with the alkali ions and with oxygen ions in complex systems of the form $Ni(OLi)_4^{2-}$, $Ni(ONa)_4^{2-}$, etc. These are most probably tetrahedral in form, with the nickel ion at the centre, the oxygens at the corners and the alkali ions at the centres or just outside the centres of the faces of the tetrahedra. These complex systems enter the glass structure in 'bridging' positions, with two of the oxygen atoms forming corners of the adjoining structure-building units. This group can be resolved into a nickel-ion 'bridge' between the two structure-building units, with the alkali ions associated with four other SiO_4 tetrahedra in the immediate neighbourhood. The two alternative configurations would form a 'resonance' system, in which the resonance point depends on the relative polarizing effects of the nickel and the alkali ions on the electron systems of the four oxygen ions or atoms associated with them.'

Nickel, Cobalt and Selenium in Pottery

H. W. WEBB: 'Cobalt, Nickel and Selenium in Pottery.'
Mond Nickel Co., Ltd., Publn. 221a,* 1956; 27 pp.

A condensed survey of available information, supported by references to the literature, and illustrated by coloured plates demonstrating the range of colouring which can be obtained by the use of these metals and their compounds, singly or in conjunction with compounds of other elements. Compositions typical of cobalt oxides and salts are tabulated.

Solubility of Graphite in Nickel

E. T. TURKDOGAN, R. A. HANCOCK and S. I. HERLITZ: 'The Solubility of Graphite in Manganese, Cobalt, and Nickel.'
Jnl. Iron and Steel Inst., 1956, vol. 182, Mar., pp. 274–7.

The solubility of graphite in pure manganese, cobalt, and nickel was determined at various temperatures up to 1700°C. The solidus temperatures of binary mixtures of carbon with manganese, cobalt, and nickel are found to be 1308°, 1319° and 1314° C., respectively: the latter two are the eutectic temperatures, the former is thought to be a peritectic temperature.

Data available on the solubility of graphite in copper and iron, together with the results now reported, indicate that the solubility of graphite in the elements of the First Long Period of the Periodic Table decreases with increase in the atomic number of the elements. The solubility is also related to the second ionization potential of the metals under consideration.

Infrared Spectrum of Nickel-Carbonyl Vapour

L. H. JONES: 'Infrared Spectrum of $Ni(CO)_4$ Vapour.'
Jnl. Chemical Physics, 1955, vol. 23, p. 2448.

Brief note on recent work done under the auspices of the U.S. Atomic Energy Commission. The observations made are considered to necessitate a change in some of the fundamental frequency requirements assigned by earlier investigators.

ELECTRODEPOSITION AND OTHER COATING METHODS

U.S. Specifications Relating to Plating

S. F. BOOTH: 'Government Specifications.'
Plating, 1956, vol. 43, Apr., pp. 490–3.

Notes on the classification of U.S. Government specifications, with particular reference to those of interest in the metal-finishing field. Sources of supply of the specifications and of relevant information are indicated.

* *We shall be pleased to supply a free copy of this publication.*

Irreversible Polarization in Electrodeposition of Nickel

H. FISCHER, M. SEIPT and G. MORLOCK: 'Oscillographic Studies on Irreversible Polarization in Electrodeposition of Nickel.'
Zeitsch. f. Elektrochemie, 1955, vol. 59, pp. 440–8.

Oscillographic methods were used to examine the decay of overvoltage at the cathode in a Watts nickel-plating bath, at very short time intervals after interruption of the current. For summary of observations made see *Chemical Abstracts*, 1956, vol. 50, Mar. 10, pp. 3117–18.

H. J. REISER and H. FISCHER: 'Oscillographic Studies of Irreversible Polarization during Cathodic Deposition of Nickel. Part II.'
Zeitsch. f. Elektrochemie, 1955, vol. 59, No. 7–8, pp. 768–72.
Chemical Abstracts, 1956, vol. 50, Feb. 25, p. 2324.

Nickel Undercoat in Silver Plating Beryllium-Copper

J. HAAS: 'Silver Plating Beryllium-Copper.'
Metal Finishing, 1956, vol. 54, Mar., pp. 48–50, 61.

The experiments reported in this paper arose out of platers' questions regarding the correct preparatory and plating treatment, with particular reference to securing good adhesion of the coating on beryllium-copper silver-plated parts which are to be soft-soldered.

Results of tests on beryllium-copper silver plated with (*a*) a copper strike, or (*b*) a copper strike + a nickel coating under the silver, demonstrate that, apart from guaranteeing perfect adhesion of the silver plating (especially during soft soldering), the advantage of a nickel undercoat is that it acts as a buffer between the highly heat-conductive silver plating and the beryllium-copper base. When the tip of a soldering iron (at about 600°F.: 315°C.), with a strip of solder, is placed against the silver plate the heat is rapidly dissipated to the copper, with the result that the solder does not flow smoothly. Nickel, however, is of low thermal conductivity, with the result that the heat of the soldering iron remains in the silver plating at the point of contact, and the solder melts quickly and smoothly. Attention is directed to the importance of pre-plating treatment of beryllium-copper parts: the composition and working conditions for various pickling solutions are given in this article.

Nickel-Dip Treatment of Steel: Radioisotope Tracer Study

J. C. RICHMOND, H. B. KIRKPATRICK and W. N. HARRISON: 'A Radioisotope Study of the Nickel Dip.'
Jnl. Amer. Ceramic Soc., 1956, vol. 39, Feb. 1, pp. 39–46.

This paper forms one of a series dealing with the bonding of ceramics to metals, which has been under study at the National Bureau of Standards for several years. Earlier papers were concerned with the

manner in which adherence develops when cobalt ions are present in the coating, and the successful use of radioactive cobalt in that research led to adoption of the same method for study of the nickel-dip process used in enamelling of steel. The results confirmed the usefulness of this test procedure.

Using radioisotope tracer technique, the following aspects were investigated:—(1) the effect of the nickel dip, on the deposition of cobalt metal during firing of a cobalt-bearing ground coat on pickled and sandblasted iron, (2) the effect of surface pre-treatment, on the amount and distribution of nickel deposited from the nickel dip on enamelling iron, and (3) the effect of application and firing of cobalt-free and cobalt-bearing enamels, on the chemical form and physical distribution of nickel previously deposited on enamelling iron by the nickel dip.

The results of the various experiments described are summarized as follows:—

'The presence of nickel from the nickel dip had little or no effect on the deposition of cobalt metal during firing of a cobalt-bearing enamel on iron.

'Type of cleaning (sandblasting or pickling) markedly affected the amount of cobalt deposited during firing of a cobalt-bearing enamel on iron. Heavier deposits occurred on sandblasted than on pickled iron.

'The distribution of the nickel from the nickel dip was always non-uniform, but the size of the areas of heavier and lighter deposits was markedly affected by the previous treatment of the metal. Heavy deposits occurred at scratches and at other areas that had been subjected to severe cold work in the surface.

'The nickel from the nickel dip remained as metal at the enamel-metal interface during firing of both cobalt-bearing and cobalt-free enamels on nickel-dipped iron. There was no evidence of oxidation of the nickel followed by solution into the enamel glass, but there was some evidence that part of the nickel was separated, probably by undercutting from the metal on continued firing.'

Hard Chromium Plating of Steel: Specification

MINISTRY OF SUPPLY: 'Hard Chromium Plating of Steel: Process Specification.'

D.T.D. 916A (superseding D.T.D. 916); Dec., 1955.

The specification is for use primarily in plating on carbon and low-alloy steels (which may or may not have been nickel plated) which require a hard surface, and for building up (salvaging) of worn or over-machined parts. It covers heat-treatment of the steel parts before plating, initial cleaning, stopping off of parts on which the chromium deposit is not required, final cleaning, etching, plating, post-plating heat-treatment, and inspection.

Appendix I gives guidance on post-plating heat-treatment suitable for eliminating hydrogen embrittlement, and for restoration of fatigue strength in the plated steel. Changes in hardness of the electro-deposited coating produced by heating at various temperatures are also shown.

Appendix II recommends procedure for analysis of chromium-plating solutions: methods for estimation of chromic acid, sulphate, trivalent chromium, and iron are detailed.

NON-FERROUS ALLOYS

Diffusion Studies on Copper-Nickel Alloys

K. TORKAR and H. H. WEITZER: 'Diffusion Study by Means of Ferromagnetic Suspensions.'

Zeitsch. f. Metallkunde, 1956, vol. 47, Mar., pp. 191–4.

The authors describe a method for revealing the boundary between a magnetic and a non-magnetic region in a metallic specimen, by means of a magnetic suspension (e.g., an aqueous solution of magnetite) which segregates at the boundaries under the influence of a magnetic field. The validity of the method is demonstrated by applying it to the study of diffusion between nickel and copper.

A report is also made of a test with nickel and copper wires, heated in contact with one another, for various periods at 860°C., in a stream of hydrogen, and examined, after various periods of heating, by means of the magnetic suspension described.

(The subject matter of this paper is closely related to that of the paper abstracted in *Nickel Bulletin*, 1955, vol. 28, No. 12, p. 206.)

Hardenable Copper-Nickel-Tin Bronzes

E. FETZ: 'Hardenable Copper-Nickel-Tin-base Bronzes.'

Metall, 1955, vol. 9, Nov., pp. 960–6.

This paper is one of a series of reports on studies of precipitation-hardening copper-base alloys, on which the author has been engaged for many years. (Earlier papers which appeared in various journals in 1935 and 1936 are referred to in the *bibliography* to the present paper.)

The experiments reported were made on four powder-produced alloys of varying nickel: tin ratios. Precipitation-hardening capacity was investigated as a function of chemical composition, compacting pressure, rate of cooling from the alpha-phase region after diffusion-sintering, pressure used in post-sintering pressing, precipitation-hardening temperature, and time of thermal treatment. The effects produced were evaluated by measurements of hardness, and determinations of volume changes and density.

The results indicate that the precipitation-hardening response in powder-produced alloys is inferior to that of alloys produced by melting and casting, but that by means of a suitable combination of mechanical working and thermal treatment it is possible to effect a useful degree of hardening.

Determination of Phosphorus in Copper-base Alloys

See abstract on p. 119.

Polarographic Determination of Nickel in Copper Alloys

See abstract on p. 101.

Cobalt-Nickel-Zinc Alloys

W. KÖSTER, H. SCHMID and E. DAHESH: 'The Structure and Hardening Capacity of Alloys of the Cobalt-Nickel-Zinc System.'

Zeitsch. f. Metallkunde, 1956, vol. 47, Mar., pp. 165–71.

The constitution of the ternary system was examined (on alloys containing 15–60 per cent. of zinc, produced by powder-metallurgical methods), by means of microscopic, X-ray and magnetic investigation.

Both magnetic and physical hardening is producible in these alloys by appropriate treatment. Maximum coercivity was of the order of 700 oersteds: the highest values were obtained at the junction of the two-phase $\gamma+\beta_1$ and the three-phase $\gamma+\beta_1+\beta_2$ regions.

Precipitation occurs somewhat irregularly. The highest coercivity is observed when the solid solution has just begun to break down. At commencement of precipitation the γ lattice tends to become tetragonally distorted, but after the maximum coercivity value is passed it again shows no distortion, and, as a result of impoverishment in zinc it has a smaller lattice constant. At that stage the interference lines of the precipitated β phases can be distinguished. It is considered that the high coercivity observed is due to a coherent type of precipitation.

Loss of Manganese in Melting Nickel-Manganese Alloys

L. SCHUMANN-HORN, A. MAGER and D. DEISINGER: 'Loss of Manganese in Melting Nickel-Manganese Alloys under Low Pressures.'

Zeitsch. f. Metallkunde, 1956, vol. 47, Mar., pp. 145–8.

In melting alloys of which the component metals have different vapour pressures and chemical reactivities, change of composition during melting has to be expected, but the extent of the change is vitally affected by the nature and the pressure of the gaseous phase present over the melt. Quantitative data on the extent of the effects exercized by these variables are of practical importance from the point of view of industrial production.

This report comprises a study of effects produced in nickel-manganese alloys (0–10 per cent. manganese) melted, in a non-oxidizing atmosphere, at 1500°–1600°C., and at pressures between $5\cdot10^{-4}$ and $5\cdot10^{-1}$ Torr. The experiments were conducted in a high-vacuum induction furnace of 10 kg. capacity, and a magnesite crucible was used. The nickel was melted down under a pressure of $5\cdot10^{-4}$ Torr and the manganese was added as a 50–50 nickel-manganese alloy.

Two practical conclusions are drawn from the observations made:—

(1) In melting alloys of the type studied argon pressure should be not less than 1 Torr: at this pressure the loss of manganese is negligible.

(2) For removal of manganese present as an impurity in a nickel melt, at 1550°C. a pressure below 10^{-1} Torr should be maintained. Evaporation is much accelerated at higher temperatures, e.g., at 1600°C. a given amount of manganese can be removed in half the time required at 1500°C.

Hall Effect in Nickel Alloys

W. F. FLANAGAN and B. L. AVERBACH: 'Hall Effect in Solid Solutions.'

Physical Rev., 2nd Ser., 1956, vol. 101, Mar. 1, pp. 1441–2.

The Hall effect was measured in gold-nickel, copper-nickel, gold-silver and copper-gold solid solutions, at 80° and 300°K. (−193° and +27°C.), as a function of composition.

Permeability of Monel Wire Cloth

E. C. YATES: 'On the Permeability of Porous Materials.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 3596, Jan., 1956; 31 pp.

Accurate and comprehensive information on the permeability characteristics of porous materials is essential to correct design of area-suction installations on wings, flaps, inlets, wind tunnels, etc. The tests reported in this publication were carried out to supply data for predicting permeability characteristics for the range of operating conditions (absolute pressure levels) to be anticipated in a wing using suction through a porous material. The material employed for the tests was rolled 30 × 250 mesh Dutch-weave Monel cloth and $\frac{1}{16}$-in. thick sintered bronze.

The results show that permeability characteristics are appreciably affected by absolute-pressure level, choking of flow, and thickness of the material. A moderate degree of bending effected no noticeable change in permeability.

Nickel-containing Materials in Jewellery

See abstract on p. 99.

Nickel, Cobalt and Selenium in Pottery

See abstract on p. 103.

Titanium-Carbide/Nickel-Molybdenum Cermets

See abstract on p. 112.

Spot and Seam Welding of Inconel W

See abstract on p. 117.

NICKEL-IRON ALLOYS

Nickel and Nickel Alloys in Digital Computers

A number of papers presented at the Convention on Digital-Computer Techniques, organized in

April 1956 by the Institution of Electrical Engineers, contained reference to the utilization of the magnetic characteristics of nickel and nickel-iron-base alloys. The whole series of papers will be published in the Proceedings of the Institution, vol. 103, Part B.

CAST IRON

Ni-Resist Cast Iron of Spheroidal-Graphite Structure (S.G. Ni-Resist)

INTERNATIONAL NICKEL CO., INC.: 'Engineering Properties of Ductile Ni-Resist Austenitic Irons.'
Issued 1955; 24 pp.

This brochure contains a comprehensive summary of data on high-alloy cast irons of the spheroidal-graphite type. The compositions, properties and applications of five irons of the group are discussed in detail, with illustrations of engineering uses for which they have already proved suitable. Among the wide range of properties characteristic of the S.G. Ni-Resist high-nickel cast irons are good resistance to corrosion by acids, alkalis and salts; toughness comparable, at ordinary temperatures, to that of steel, and well retained at lower temperatures; ductility; resistance to heat and oxidation, and to wear and erosion. The fluidity of these irons permits production of intricate designs, and their machining qualities are of the same order as those of conventional pressure-type grey cast iron. By suitable selection of composition within the group, thermal-expansion values can be controlled, over a wide range, within close limits, and the non-magnetic quality obtainable in some of the irons is an added advantage for certain applications in the electrical and allied fields.

Elevated-Temperature Properties of S.G. Iron

F. B. FOLEY: 'Mechanical Properties, at Elevated Temperatures, of Ductile Cast Iron.'
Amer. Soc. Mechanical Engineers, Paper No. 55-A-204, Nov., 1955; 6 pp. + figures.

In view of the increasing interest in the elevated-temperature properties of engineering materials, published and some unpublished data on S.G. cast iron have been assembled and correlated. Results of stress-rupture, creep and short-time high-temperature tests reported by various investigators are tabulated, with indication of the source of the original information. From these data have been derived average values, shown in the table on p. 107.

These values may be regarded as close approximations of those to be expected from wholly ferritic S.G. iron. The presence of combined carbon will tend to raise them, particularly in the lower temperature range: from this point of view, therefore, the figures given in the table may be regarded as minima.

Nickel-Alloy and S.G. Irons in Mining Equipment

J. E. REHDER: 'Iron Castings. Application and Proper Selection for the Mining Industry.'
Canad. Mining and Metallurgical Bull., 1956, vol. 49, Mar., pp. 175–179; *Trans. Canad. Inst. Mining and Metallurgy*, 1956, vol. 59, pp. 107–11.

It is pointed out that in selecting any material of construction the final criterion must be unit cost *vs.* service performance, and that since grey cast iron is the lowest-cost constructional material it should be used unless there is some clear indication, on engineering grounds, in favour of a material of higher cost. Such grounds are the requirement for improved shock-resistance, higher strength, lighter weight and, in certain cases, better corrosion-resistance.

With this proviso, the author reviews the properties of ordinary grey cast iron, giving some applications typical of its many uses in the mining industry. Properties of white irons are next considered, and their application in service for which wear-resistance is required, e.g., ball-mill liners, grinding equipment, crusher parts, etc. In the section relating to alloy irons, the usefulness of nickel additions is emphasized: attention is directed to the value of Ni-Hard as an abrasion-resisting material, and of the higher-alloy iron, Ni-Resist, for resistance to corrosion and heat. Malleable iron is next considered, and the final section of the review deals with 'nodular', or 'ductile' iron (spheroidal-graphite iron), which, by virtue of its enhanced toughness and other mechanical properties, has opened up to the foundry industry applications hitherto unthought of for cast iron. The properties characteristic of the material, in the as-cast (pearlitic) and in the annealed (ferritic) conditions are outlined, and reference is made to U.S. standard specifications governing this product. Emphasis is placed on the range of properties obtainable in S.G. irons, according to their condition and treatment, a feature which fits them for correspondingly wide application in the mining and other engineering industries. Potential applications fall into three broad categories:

(1) for re-design of castings now made in grey cast iron, with possible decrease of section thickness and valuable increase in toughness,

(2) for castings in which toughness and shock-resistance superior to that of grey cast iron are called for, and for which, until now, the only alternative has been the use of steel,

(3) for applications in which the unusual combination of properties obtainable in S.G. iron fits it particularly well for specific applications, e.g., the possibility of providing a white-iron surface with high-strength core, or the possible combination of high mechanical strength with good machinability.

As specific examples of the successful applications of S.G. iron, the author quotes the following:—swing hammers with white-iron faces, crusher rolls, crankshafts, journals, machinery frames and other components, gears of all sizes.

Temperature		Short-Time Tensile		Stress-to-Rupture in			Stress for Creep Rate (% per 1,000 hrs.)	
°F.	°C.	T.S. p.s.i. (t.s.i.)	Y.S. p.s.i. (t.s.i.)	1,000 hrs. p.s.i. (t.s.i.)	10,000 hrs. p.s.i. (t.s.i.)	100,000 hrs. p.s.i. (t.s.i.)	0·1% p.s.i. (t.s.i.)	0·01% p.s.i. (t.s.i.)
70	21	65,300 (29·15)	46,000 (20·55)	—	—	—	—	—
700	371	55,800 (24·9)	35,400 (15·8)	36,000 (16·1)	30,000 (13·4)	24,000 (10·7)	25,100 (11·15)	19,000 (8·47)
800	426	48,600 (21·7)	34,100 (15·25)	23,000 (10·25)	17,000 (7·6)	12,300 (5·5)	12,800 (5·7)	8,700 (3·86)
900	482	40,000 (17·85)	29,000 (12·95)	13,000 (5·8)	9,100 (4·1)	6,400 (2·86)	6,000 (2·67)	3,900
1000	538	29,750 (13·3)	24,000 (10·7)	7,100 (3·2)	4,900	3,350	2,800	1,800
1100	593	19,000 (8·5)	17,500 (7·82)	3,900	2,620	1,760	1,350	—
1200	648	10,800 (4·8)	10,400 (4·65)	2,190	1,450	920	—	—

CONSTRUCTIONAL STEELS

Ultra-High-Tensile Nickel-Alloy Steels

J. W. SANDS and O. O. MILLER: 'Ultra-High-Strength Steels: Present and Future.'

Materials and Methods, 1956, vol. 43, Mar., pp. 94–8.

Reprint issued by INTERNATIONAL NICKEL CO., INC., 1956.

This article lists the compositions and properties of steels which have been developed, or are now under investigation, to meet specification requirements of the order of 100–150-ton tensile strength. It is stated that steels of the 120-ton type are already in use in aircraft and that some types giving strengths in the region of 150 tons are showing promise in experimental study: see table on p. 108.

It is pointed out that the approach to the problem of obtaining high strength without undue sacrifice of ductility has been made along two lines: firstly, by full exploration of the properties obtainable by variation in the composition and heat-treatment of modified standard steels of the nickel-chromium-molybdenum S.A.E. 4340 type, and secondly by development of compositions 'tailored' to ensure the requisite combination of strength and toughness. In the latter class raising of the silicon content has been an important factor. In the earlier stages of this development the tendency was to use the lowest feasible carbon content, but more recently the goal of still higher tensile strength has brought about reversion to a carbon level of at least 0·4 per cent.

In the modified S.A.E. 4300 types of steel a low tempering temperature (400°–450°F.: 205°–230°C.) is necessary, in order to ensure the optimum combination of strength and toughness, and with all the ultra-high-strength types it is essential to avoid tempering in the embrittling range. Increase in the silicon content, however, in addition to retarding softening on tempering, shifts initiation of embrittlement to a higher range, and a tempering temperature of the order of 600°F. (315°C.) is optimum for the higher-silicon steels. The effect of silicon, at normal and higher levels, is illustrated in this paper by reference to a typical nickel-chromium-molybdenum-base steel tempered at 500°F. (260°C.).

Particular attention is directed to one of the newest of the ultra-high-tensile steels, Tricent, which originated in the laboratories of The International Nickel Company, Inc. This composition (see table) is the result of combining three of the features which have proved significant in steels which are already established: (1) retention of the 0·4 per cent. carbon level, (2) modification of composition, *viz.*, increased manganese and molybdenum, and (3) the use of high silicon. Production heats have confirmed results obtained in the laboratory and the steel has also shown outstanding properties in a series of comparative tests made by Wright Air Development Center on landing-gear forgings. The results of tensile, notch-tensile, impact and bend tests, at room and at sub-zero temperatures, indicate that strengths approaching 134 tons per sq. in. are obtainable without significant loss in ductility. It is pointed out that these data (tabulated in the paper) were determined on full-sized, regularly processed components and that they merit careful consideration, as indicating typical properties more reliably than values obtained from test stock which is not fully representative of the end product.

Table I

Type	S.A.E. (A.M.S.) No.	Average Composition							U.T.S.	
		C %	Si %	Mn %	Ni %	Cr %	Mo %	V %	p.s.i.	t.s.i.
Used in 1955 *Production Aircraft*										
4340	6415	0·40	*	0·75	1·83	0·80	0·25	—	270,000	121
4330 Modified	6427	0·30	*	0·90	1·83	0·85	0·43	0·08	250,000	112
HS-220 ..	6407	0·30	0·55	0·70	2·05	1·20	0·45	—	230,000	103
Hy-Tuf ..	6418	0·25	1·50	1·35	1·83	0·30	0·40	—	230,000	103
Under Investigation										
4350		0·50	*	0·75	1·83	0·80	0·25	—	300,000	134
HS–260		0·40	0·60	0·85	2·20	1·45	0·50	—	290,000	130
Super Hy–Tuf		0·40	2·30	1·30	—	1·40	0·35	0·20	300,000	134
Hi–C Super Hy–Tuf ..		0·47	2·42	1·28	—	1·11	0·42	0·25	325,000	146
98B40 Modified		0·40	*	0·75	0·85	0·80	0·20	Boron	290,000	130
USS Strux		0·43	0·55	0·90	0·75	0·90	0·55	Boron	290,000	130
Tricent		0·43	1·60	0·80	1·83	0·85	0·38	0·08	300,000	134
Super Tricent		0·55	2·10	0·80	3·60	0·90	0·50	—	340,000	152

* Normal silicon 0·20–0·35%.

Low-Alloy High-Strength Pressure-Vessel Steels

J. H. GROSS and R. D. STOUT: 'The Performance of High-Strength Pressure-Vessel Steels.'
Welding Jnl., 1956, vol. 35, Mar., pp. 115S-19S.

Recent developments in pressure-vessel applications involve marked increase in operating pressures, resulting in a need for increase in section thickness of vessels made in the conventional plain carbon pressure-vessel steel. (It is considered that if this trend continues thicknesses in excess of 12 in. may ultimately be necessary.) Such increase in section gives rise to many problems in manufacture, forming, welding, heat-treatment and transportation. With a view to solving these problems, the Pressure Vessel Committee of the Welding Research Council has initiated a two-fold investigation: (1) study of improved methods of design, with the object of increasing permissible design stresses, and (2) examination of the suitability, for pressure-vessel construction, of steels having strengths considerably above those of the carbon steels now used. Several steels having tensile strengths above the 60,000 p.s.i. (27 tons per sq. in.) typical of the carbon steel have been approved in the U.S.A. for this purpose, but information on service behaviour is not yet available, and the laboratory study now reported was undertaken in order to provide data which would warrant use of higher-tensile steels in the relatively near future.

Six steels, two each of the 50,000, 70,000 and 90,000 p.s.i. (22·5, 31·25 and 40 tons per sq. in.) yield-strength classes were chosen for test, in comparison with standard carbon pressure-vessel steel. The material was used in the form of 1-in. thick plate, and the examination comprised (*a*) determination of the mechanical and related properties of the plate, in various conditions of heat-treatment, and at various temperatures up to 750°F. (400°C.), and (*b*) study of the effect of fabricating operations on the steels.

The compositions of the materials so examined are shown in the table on p. 109.

A detailed report is made of the results of the respective series of tests, including effects of strain ageing, of stress-relief treatment and of welding, on the notch-toughness of the steels. The results lead to the following conclusions:—

The high-strength steels examined compare favourably with the conventional carbon pressure-vessel steel. As was to be expected, their strength, both at room temperature and at elevated temperatures, is considerably above that of the carbon steel: elongation values are correspondingly lower, and the significance of this factor will require further investigation. It is considered that, if design is based on yield strength, the fall in this property with rise in temperature may call for some reduction in design stress for elevated-temperature operation.

The higher-tensile steels can be satisfactorily welded by procedures developed for that class of material. There is, however, a somewhat greater tendency to

Chemical Analysis of Low-Alloy Pressure-Vessel Steels

Steel	C %	Si %	S %	P %	Mn %	Ni %	Cr %	Mo %	V %	Ti %	Cu %	B %
A201	0·11	0·16	0·030	0·014	0·44	—	—	—	—	—	—	—
48s5HT	0·15	0·18	0·028	0·033	1·09	0·06	0·06	0·02	0·09	0·009	0·11	—
A302	0·20	0·25	0·030	0·022	1·32	—	—	0·42	—	—	—	—
70B	0·16	0·05	0·037	0·012	0·63	1·47	0·04	0·23	—	—	1·02	—
70A	0·12	0·21	0·032	0·013	0·48	2·16	0·06	0·39	0·11	—	0·70	—
90A	0·30	0·22	0·020	0·013	1·49	0·06	—	0·12	—	—	—	present
90B	0·15	0·27	0·022	0·015	0·93	0·89	0·48	0·44	0·06	—	—	0·0031

cracking than is characteristic of the carbon steel, and careful control of all welding variables is essential.

Notch-toughness of the higher-tensile steels is usually equal to, or better than, that of the conventional pressure-vessel steel, but there is a tendency to embrittlement after stress-relief treatment, which calls for special precautions in fabrication.

Of the steels studied, 90B (see table) shows the greatest promise for this application. By comparison with the typical carbon steel, it shows (*a*) twice the tensile strength, three times the yield strength, half the ductility; (*b*) equally satisfactory elevated-temperature tensile properties; (*c*) only slightly greater tendency to cracking in standard cracking tests; (*d*) substantially superior notch-toughness in all conditions; (*e*) minimum susceptibility to base-metal embrittlement.

It is emphasized that these conclusions are based solely on laboratory tests which do not reproduce service conditions, and that the data are not intended for use in design. Some indication of the probable service performance of the high-strength steels can, however, be inferred from a comparison of their behaviour with that of the standard pressure-vessel steel in the simulated tests used in this investigation, combined with existing service records for the carbon steel.

Nickel-Alloy Steels in the Mining Industry

T. G. BRADBURY: 'Wrought Steel: Its Choice and Application for the Mining Industry.'

Canad. Mining and Metallurgical Bull., 1956, vol. 49, Mar., pp. 167–74; *Trans. Canad. Inst. Mining and Metallurgy*, 1956, vol. 59, pp. 99–106.

General notes on the enhancement of mechanical and physical properties which can be achieved by suitable alloying of steel are followed by specific reference to items of mining equipment in which such enhanced properties are utilized. Particular interest attaches to high-tensile low-alloy steels in which mechanical strength is associated with improved resistance to corrosion by atmospheric and other conditions liable to be present in mines. From among the examples cited, the following are of major interest:—

(*a*) High-strength low-alloy steels for heavy-duty power shovels, in which one of the most important design features is a high strength/weight ratio in the boom and dipper assembly.

(*b*) Use of phosphorus-copper-nickel high-tensile corrosion-resisting steel in skip liners handling ore and coke, where a life of nearly three times that of carbon-steel liners has been obtained.

(*c*) Power shovels, dipper sticks and other parts operating at sub-zero temperatures, in which the greater toughness characteristic of nickel-alloy steels provides insurance against brittle fracture liable to occur with carbon-steel components.

(*d*) Wear-resisting parts, in which medium manganese steels (or, in some cases, high-manganese steel) can be used with advantage.

(*e*) Components of pneumatic drilling machines, e.g., pistons, which may operate at more than 2,000 blows per minute, thus imposing on the constructional materials severe requirements with regard to strength and toughness. For such service, nickel and nickel-molybdenum carburizing steels are generally favoured: they have given excellent service in cylinders, chucks and sleeves, valves and bushings, pawls, ratchets and other parts. A vanadium-bearing carbon steel is also in use for pistons and tappets. With the increasing tendency to use of detachable bits, higher-tensile steels are employed for the shanks: nickel-chromium-molybdenum and chromium-molybdenum types have both been found suitable for this purpose, but the nickel-containing type is to be preferred, as showing higher elastic properties, and therefore greater resistance to bending, and as being less notch-sensitive. For churn drill bits, also, a nickel-chromium-molybdenum steel is favoured: comparative service data on bits made from such steel, with records for carbon-steel bits, demonstrate the advantages of the alloy grade.

(*f*) Increasing amounts of sling and crane chain are being made from alloy steels: nickel-molybdenum types are the most generally used. Weight saving, absence of embrittlement from work-hardening, and maintenance of good impact-resistance at sub-zero temperatures are among the advantages gained.

(*g*) For coil springs, in which high mechanical properties and good resistance to fatigue are essential, chromium-manganese, manganese-silicon and low-alloy nickel-chromium-molybdenum steels are among the types employed. Although, in an identical surface condition, carbon spring steel shows fatigue properties equal to those of the alloy grades, the latter have, in general, better hardenability, higher yield strength, and lower notch-sensitivity.

(*h*) Conditions in which shafting and axles operate vary so widely that the choice of steel may range from a plain carbon type to a nickel-chromium-molybdenum steel heat-treated to a high tensile strength. Properties typical of four grades of steel employed for such components are given in the paper.

(*i*) Reference is made also to materials for parts operating in corrosive waters, and examples of the use of nickel-chromium stainless steels in pumps, valves, exhaust fans and weir parts are quoted.

The review closes with a comprehensive summary table showing steels in current use for components of mining equipment of the following types: mine and transfer cars; loading pockets and ore chutes; skips and cages; feeders, conveyors and vibrating screens; power shovels; crushers (jaw, gyratory, and cone); pneumatic drills, and miscellaneous components. Specification compositions (A.I.S.I.) are quoted for all the steels to which reference is made. The information given is based on the practice and experience of twelve representative producers and users of mining equipment.

Nickel-Molybdenum Steel Electrodes for Welding High-Tensile Steels

G. S. WEPFER: 'The Development and Investigation of High-Tensile High-Impact Electrodes.' *Welding Jnl.*, 1956, vol. 35, Mar., pp. 229–35.

The primary objective of the work described was evaluation of the suitability of established electrodes for welding low-alloy steels of the T-1 and vanadium-containing nickel-chromium-molybdenum S.A.E.4340 types, and development of an electrode composition ensuring satisfactory properties in welded joints in such steels. (An average composition of T-1 steel is given as carbon 0·18, silicon 0·38, manganese 0·95, nickel 0·84, chromium 0·56, molybdenum 0·56, vanadium 0·07, copper 0·29, boron 0·004, per cent.).

Standard commercial electrodes were found to be inadequate, and experimental nickel - vanadium (1·8/0·3%) and nickel-molybdenum (1·8/0·8%) types, i.e., modified A.S.T.M. E.12015 electrodes, also failed to meet requirements, due to low impact properties in the welded joints at sub-zero temperatures.

Tests were then made with a series of experimental electrodes, using a low-hydrogen type of coating: for wire compositions see table I below.

Examination of the properties of welds made with the respective types of experimental electrode led to the following conclusions:—

Types A, B, C, F, H and J were unsatisfactory, due to low impact strength in the welded joints at sub-zero temperatures. Electrodes of D type gave welds low in yield and tensile strength, but the impact properties of the joints made with this composition were the highest found. Types E and F gave erratic sub-zero impact values in the weldments, indicating that at −65°F. (−54°C.) they were in the transition range. Electrode G was tested in various diameters, and good results were obtained: see typical values in Table II on p. 111.

It will be noted that there is very little difference between the as-welded and the stress-relieved yield and tensile strengths of welds made with this electrode. In evaluation of impact properties, the V-notch Charpy impact test was found to be a more critical test than the keyhole-notch Charpy test.

The G type of electrode has been found to give satisfactory results in fabrication of various thicknesses

Table I Experimental Electrodes

Type	Mn %	Ni %	Mo %	Cr %
(1) A	1·00	1·75	—	—
B	1·25	1·75	—	—
C	2·00	2·25	—	—
D	1·00	3·25	—	—
(2) E	1·50	1·75	0·20	—
F	1·00	2·00	0·50	—
G	1·00	3·50	0·50	—
H	0·75	3·25	0·75	—
(3) I	1·00	3·00	—	0·50
J	1·00	3·25	—	0·75

Table II

Composition of Electrode (G Type)

C %	Si %	Mn %	Ni %	Mo %	V %
0·06	0·29	0·96	3·30	0·64	0·02

Mechanical Properties

Condition of Weld	Yield Strength		Tensile Strength		Elongation in 2 in.	Reduction of Area
	p.s.i.	t.s.i.	p.s.i.	t.s.i.	%	%
As welded	96,150	43·0	109,650	48·95	21·6	55·1
Stress-relieved	98,150	43·8	110,150	49·15	23·0	58·6

V-notch Charpy Impact Properties

	As-welded						Stress-relieved					
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Testing temperature	75	24	0	−18	−65	−54	75	24	0	−18	−65	−54
	77·8		52·5		33·7		62·8		35·7		19·4	

Keyhole Charpy Impact Properties

	As-welded						Stress-relieved					
	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.	°F.	°C.
Testing temperature	75	24	0	−18	−65	−54	75	24	0	−18	−65	−54
	37·0		34·1		31·5		35·9		30·3		24·6	

of T-1 plate up to 1½ in., in repair-welding of high-tensile steel crankshafts, in fabrication of homogeneous armour plate, and in repair-welding of high-tensile steel castings.

Spectrographic Analysis of Nickel-Alloy Steels

H. T. SHIRLEY, A. OLDFIELD and H. KITCHEN: 'A Comparison of Three Methods of Plate Calibration and Evaluation for Routine Spectrographic Analysis of Low-Alloy Steels.'

Spectrochimica Acta, 1956, vol. 7, Mar., pp. 373–86.

A report is made of a comparative study of three procedures for plate-response calibration and general evaluation of low-alloy steel spectrograms.

(*a*) based on the direct relation of densitometer readings to log-relative intensity,

(*b*) using the Kaiser-Seidel-transformation (*P*-value) technique for straightening the plate-response curve,

(*c*) by means of the $-f(\tau)$ transmittance table of J. W. Anderson (*Applied Spectroscopy*, 1953, vol. 7, pp. 121–4).

For this work a series of ten working plates, taken over a period of a year, provided a total of fifty spectrograms for each of two low-alloy B.I.S.R.A. steel standard samples having the compositions shown on p. 112.

	Mn %	Ni %	Cr %	Mo %	V %	Cu %
No. 3	0·36	2·92	0·35	0·95	0·22	0·50
No. 6	1·21	0·18	2·34	0·54	0·36	0·23

It is shown that an improvement in analytical accuracy (standard error), of the order of 20 per cent. may be expected from the use of methods (*b*) and (*c*) with individual plate calibration, as compared with method (*a*) and batch calibration. About one-third of this improvement was from individual plate calibration.

Speed and ease of working is considered generally similar for the three methods, but plate-response calibration is markedly simplified by the straight-line relationships of methods (*b*) and (*c*).

Determination of Phosphorus in Stainless and Other Steels

See abstract on p. 119.

HEAT- AND CORROSION-RESISTING MATERIALS

Influence of Cyclic-Temperature Conditions on Mechanical Properties and Creep

E. E. BALDWIN: 'The Stress-Rupture Strength of Type 347 Stainless Steel under Cyclic Temperature.' *Trans. Amer. Soc. Mechanical Engineers*, 1956, vol. 78, Apr., pp. 517–25.

Evidence from various sources has clearly established that while at constant temperature rupture and creep strengths of given materials are predictable and reproducible, they are seriously affected by cyclic temperature changes. Literature relating to observation of typical changes so produced is referred to by the author, and the significance of the effects resulting from cycling of temperature is urged, as affecting service life of power-station plant.

The investigation reported in this paper was undertaken to determine the effect of several types of cyclic-temperature changes, on the stress-rupture strengths of niobium-stabilized 18–10-type chromium-nickel steel, and to compare the test results with values of cyclic-temperature rupture life calculated by the method proposed by ROBINSON and MILLER (*ibid.*, 1952, vol. 74, pp. 777–81 and *A.S.T.M. Special Publication* No. 165, 1954, p. 53). The observations made were also to be used in an attempt to deduce an explanation for any deviation of experimental from calculated results.

The tests were of three types: (1) cyclic-temperature stress-rupture tests in sodium; (2) constant-temperature stress-rupture tests in sodium, and (3) short-time tensile tests in air. (Records of other constant-temperature tests in air were also available for comparison.)

The cycling of temperature was as follows:—(1) variation in a saw-tooth cycle (continual fluctuation between an upper and a lower temperature limit), and (2) variation in a square-wave cycle (upper and lower temperature limits, with a period of holding at each limit). For the constant-temperature series the range was 1000°–1200°F. (538°–648°C.), and the cyclic-test temperatures were from 416° to 1294°F. (214°–700°C.), with times varying from 6 to 12 hours. Short-time tensile tests were made at room temperature and at 200°, 400°, 600°, 800° and 1000°F. (93°, 204°, 315°, 426° and 538°C.).

Full details are recorded for each test series, and photomicrographs show the structure of typical specimens of the steel in various conditions.

The general conclusion is that the mathematical expressions developed by ROBINSON (*loc. cit.*) for calculating the stress-rupture life of steels under cyclic-temperature conditions give results which are only an approximation of the expected life. Deviation of the actual from the calculated life is believed to be due to the transient creep conditions which exist during cyclic-temperature changes, of which the Robinson and Miller formulae take no account. It is emphasized that the rupture life determined under a given cyclic-temperature condition, for the type of steel studied, is valid only for that condition and that it cannot be extrapolated to similar conditions with any degree of accuracy.

Titanium-Carbide/Nickel-Molybdenum Cermets

M. HUMENIK and N. M. PARIKH: 'Cermets. I. Fundamental Concepts Related to Microstructure and Physical Properties of Cermet Systems.' *Jnl. Amer. Ceramic Soc.*, 1956, vol. 39, Feb. 1, pp. 60–3.

In considering the fundamental principles governing structure and consistency of cermets it is realized that the distribution of the metal phase plays a major rôle, and that further knowledge of the factors controlling this dispersion is essential to development of the respective types of cermet. When a homogeneous carbide and metal-powder mixture is cold-pressed and densified at elevated temperatures in the presence of a liquid phase the ultimate distribution of the metal will depend primarily on the wettability of the solid phase, which, in turn, is dictated by the various interfacial energies of the system. The work reported in this paper deals with the evaluation of tungsten-carbide- and titanium-carbide-base cermets on the basis of wettability of the carbide phase.

In studying titanium-carbide/nickel cermets it was observed that large apparent grain growth occurred during sintering, and correlation of these observations with those made on tungsten-carbide/copper cermets indicated that the apparent grain growth in the nickel-bound cermets might be due to coalescence of the carbide phase resulting from an incomplete wetting action of the liquid metal phase. It appeared likely that improved properties might be obtainable in titanium-carbide-base cermets by formation of a completely dispersed carbide structure, and with a view to achieving such dispersion, wettability studies

were made on cermets in which binary nickel alloys containing 10 per cent. by weight of titanium, chromium, manganese, zirconium, niobium, vanadium, tantalum, tungsten, or molybdenum were used as binders. Molybdenum additions to nickel resulted in complete wettability on titanium carbide, but the mechanism of the action is not yet understood.

In hardness tests on nickel-molybdenum-bound titanium-carbide cermets data were obtained on specimens containing (60%TiC–40%Ni+Mo), with the molybdenum content ranging from 1·5 to 50 per cent. of the metal phase. Significant increase in hardness is obtained with molybdenum up to 5 per cent., but further additions have no appreciable influence. Determinations of impact resistance, on tungsten-carbide/cobalt and titanium-carbide/nickel-molybdenum cermets, indicate that the latter show a marked improvement by comparison with earlier types of cermet, and that with relatively high content of the alloy binder the impact properties of the composite approximate those of alloy X-40* in the aged condition.

Stainless Steels: Types Recently Developed

D. B. ROACH and A. M. HALL: 'The New Stainless Steels.' *Materials and Methods*, 1956, vol. 43, Apr., pp. 137–52. M. and M. Manual No. 126.

This Manual, one of the series on engineering materials regularly published by this journal, gives data on composition, treatment, properties and uses of some of the newer types of stainless steels. The review includes information on:—

(1) high-manganese grades of the austenitic chromium-nickel steels;

(2) extra-low-carbon varieties of regular chromium-nickel stainless types;

(3) precipitation-hardenable chromium-nickel-base steels containing aluminium, titanium, niobium, tantalum, copper, phosphorus and other elements, used in varying combination;

(4) ferritic stainless steels intended for high-temperature applications.

Precipitation-Hardening Stainless Steel and Titanium Alloy: Comparison of Properties

R. G. SLOAN: 'Stainless *vs.* Titanium for High-Speed Aircraft.'

Materials and Methods, 1956, vol. 43, Apr., pp. 124–7.

Conditions to which materials are subject in supersonic aircraft are such as to preclude the use of most constructional metallic materials. Precipitation-hardening stainless steel of the 17-7 chromium-nickel type and certain titanium alloys alone qualify for consideration for this purpose, and the object of the present article is to make comparison of these two types of material, on the basis of individual properties which are significant in aircraft construction. Graphs show the characteristics of typical titanium-base materials and 17-7 steel as revealed by test results relating to:—

short-time tension and compression
short-time bearing strength
shear strength
tensile and compressive moduli
short-time creep strength
creep stress
stress to rupture.

It is noted that research on precipitation-hardening stainless steel is still under way, and that results obtained to date indicate the likelihood of substantial improvement being effected in both room and elevated-temperature mechanical properties.

* Cobalt-chromium-nickel-base alloy containing tungsten.

British Standard Specifications for High-Alloy Steels for Aircraft

'Cold-Rolled Chromium-Nickel Steel Sheets and Strips (Corrosion-Resisting) (40-ton 0·1 per cent. Proof Stress).'

B.S. S. 520, Mar., 1956.

The chemical requirements are as follows:—

	Min. %	Max. %
Carbon	—	0·16
Silicon	0·20	—
Manganese ..	—	1·0
Nickel	7·0	12·0
Chromium ..	16·0	20·0
Titanium	5 × C	—
or		
Niobium ..	10 × C	—
Sulphur	—	0·045
Phosphorus ..	—	0·045

Tungsten, molybdenum, tantalum, copper, vanadium, may be present at the option of the manufacturer.

It is specified that the steel shall be manufactured by an electric process, that it shall be supplied either cold-rolled or cold-rolled and tempered, and that it shall satisfy tensile, bend and weld-decay tests which are specified.

See also—

'Chromium-Nickel Steel Sheets and Strips (Corrosion-Resisting) (13-ton 0·1 per cent. Proof Stress).'

B.S. S. 521, Mar., 1956.

This specification covers steel of the same composition as that covered by S. 520, but in the softened condition, as obtained by heating to a temperature of not less than 950°C. and cooling in air or quenching in water.

'23-14 Chromium-Nickel Steel Sheets and Strips (Heat-Resisting).'

B.S. S. 522, Mar., 1956.

The material, which is to be supplied in the softened

condition (see previous specification), is of the following type:—

	Min. %	Max. %
Carbon	—	0·16
Silicon	0·20	—
Manganese ..	—	1·0
Nickel	12·0	16·0
Chromium ..	20·0	26·0
Titanium ..	5 × C	—
or		
Niobium ..	10 × C	—
Sulphur	—	0·045
Phosphorus ..	—	0·045

Tungsten, molybdenum, tantalum, copper, vanadium, may be present at the option of the manufacturer.

Tensile, bend and weld-decay tests are specified.

See also—

'23-18 Chromium-Nickel Steel Sheets and Strips (Heat-Resisting).'

B.S. S. 523, Mar., 1956.

Compositional requirements are as for S.522, except that nickel is 16·0–20·0. The material is supplied in the softened condition (see above).

Stress Corrosion of Stainless Steels in High-Temperature Water

W. L. WILLIAMS and J. F. ECKEL: 'Stress Corrosion of Austenitic Stainless Steels in High-Temperature Water.'

Jnl. Amer. Soc. Naval Engineers, 1956, vol. 68, Feb., pp. 93–104.

This paper comprises a much condensed version of selected information from a chapter on stress corrosion which is to be included in a Wear and Corrosion Handbook for Water-Cooled Reactors. The Handbook is being prepared, under contract with the U.S. Navy, by Westinghouse Electric Corporation: it is scheduled for publication early in 1956.

As an introduction to the condensed report of experimental work, the nature of stress corrosion is briefly discussed, appropriate literature is reviewed, and theories of stress corrosion are considered. From a correlation of some typical cases of stress corrosion which have been reported in industrial plant, the following conclusions were drawn:—

'(1) Chlorides were present in all instances and have been considered the cause of stress corrosion. In each case, a condition existed that favoured concentration in the region where failure by cracking occurred. Therefore, the existence of conditions favouring concentration may be a more important consideration than the actual overall composition of the water.

'(2) In many cases, changes in design, construction or operational procedures which eliminated or minimized concentration were successful.

'(3) No information on the amount of oxygen present was available. In view of experimental results discussed below, the effect of oxygen concentration cannot be neglected.

'(4) All cracking was transgranular in nature.'

The research was therefore directed towards study of the conditions in which stress corrosion can occur. The influence of numerous variables was investigated, but the experimental data recorded in this report are restricted to information essential to clear understanding of the results. The material presented is arranged in two main sections: (1) tests of small laboratory specimens, to determine the effects of variations in material and in environment, and (2) tests of small boilers, to confirm the laboratory results under more realistic conditions.

Although the programme of laboratory tests was not primarily directed towards a study of the fundamental nature of stress corrosion, the results made some contribution towards an understanding of the conditions in which austenitic stainless steels will or will not be subject to stress-corrosion damage. The observations made in all the tests are considered to warrant certain general and specific conclusions, the main points of which are summarized below. (It should be noted that in all cases the steels referred to are austenitic chromium-nickel types.)

Available evidence indicates that stress-corrosion cracking will very rarely, if ever, occur in major structural components of high-purity water systems. Such components would be normally fabricated from annealed material.

Heavy cold working, however, appears to cause susceptibility to stress corrosion in high-purity water, particularly oxygen-bearing water.

Stress-corrosion behaviour of austenitic stainless steels in boiler-water conditions is a considerably more critical problem, due mainly to the chlorides which may be encountered in steam-generating systems, especially naval boilers. The austenitic steels as a class appear to be susceptible to stress-corrosion cracking in high-temperature chloride-containing water. Some types are more resistant than others, but insufficient work has yet been done to permit reliable assessment of relative resistance.

Cracking in stress corrosion is predominantly transgranular: sensitivity to intergranular corrosion is not necessary, but sensitized steels can fail by stress-corrosion cracks following an intergranular path.

The transgranular stress-corrosion cracks vary in appearance from single, relatively straight, cracks to highly-branched finger-like crack networks. Stress-corrosion cracks usually start at corrosion pits, but all environments leading to corrosion pits do not necessarily lead to stress-corrosion cracks. Stabilization of the austenite by moderate increase of

nickel does not prevent stress corrosion, but probably increases resistance to cracking.

The thickness of a stress-corrosion specimen has no noticeable effect on susceptibility to cracking. Statically applied stresses as low as 5,000 p.s.i. (2·5 tons per sq. in.) can cause stress corrosion of an austenitic steel in certain environments, and residual stresses from tube rolling, cold forming, etc., are sufficient to cause failure in conditions which are highly conducive to stress corrosion.

Stress corrosion may occur at temperatures as low as the boiling point of water, and probably at even lower temperatures. It is probably accelerated by rise in temperature. Onset of stress corrosion may be rapid under highly conducive conditions: specimens have been observed to fail within a few minutes at 500°F. (260°C.)*. Stress corrosion can occur in uninhibited water containing a moderately small amount of chloride: specimens immersed in oxygen-bearing water containing 300 p.p.m. chloride were readily attacked, while similar tests in chloride-free water did not result in cracking.

Stress corrosion of steels submerged in chloride-bearing water can be prevented by alkaline phosphate treatment of the water, provided that the steels are in the annealed condition at the time of fabrication, and that sensitization does not occur as a result of welding or operating temperatures. Steels exposed in the steam phase of chloride-bearing water, and intermittently wetted, are susceptible to stress-corrosion cracking at very low chloride contents, e.g., from water containing as little as 1 p.p.m. chloride. The alkaline-phosphate water treatment does not inhibit stress corrosion of the steels in the steam phase of boiler water.

Oxygen is a strong accelerator of stress corrosion of the steels in hot-water environments, and it is probable that some oxygen is necessary for stress corrosion to occur, although the amount needed may be small. Maintenance of low oxygen content may not be an entirely satisfactory method of preventing intergranular stress corrosion in unstabilized sensitized steel, but this problem would not be anticipated with stabilized steel.

Vapour-phase inhibitors offer some promise as a means of controlling stress corrosion. Sulphite treatment appears specially beneficial. It is probable that any successful inhibitor will have oxygen-scavenging characteristics.

The principal value of the work done was to emphasize the need for extreme caution in design and operation of equipment in which austenitic stainless steels are used in contact with high-temperature water, especially the steam phase of such water. It is concluded that much can be accomplished by correct design and by operation of equipment within safe limits.

The use of annealed steels, stress-relief treatments, stabilized types of steel, low operating stresses, low levels of chloride and of oxygen, and suitable corrosion inhibitors are all important as means of eliminating stress-corrosion hazards.

* *Plus heating and cooling time.*

Corrosion-Resistance of Titanium-Stabilized Chromium-Nickel Steels

E. J. HEELEY and A. T. LITTLE: 'Corrosion-Resistance of Some Austenitic Cr-Ni Steels of 18-8-Ti Composition. The Effect of Variation in Chemical Composition and Thermal Treatments.'

Jnl. Iron and Steel Inst., 1956, vol. 182, Mar., pp. 241-55.

The research described in this paper centred on behaviour of welded 18-8-Ti steels used in construction of chemical plant handling nitric-acid liquors. Service experience had indicated that corrosion-resistance of such steels may be impaired by exposure to temperatures involved in welding, and that the damage may occur in two zones, (*a*) in the area which has been subjected to a temperature between about 1300°C. and the melting point of the steel, and (*b*) in areas which have been exposed to a temperature in the range 600°-750°C. The former condition had been found to give rise to 'fissuring', the latter to 'grooving': illustrations of both types of defect are given in the paper. The lowered corrosion-resistance in zones adjacent to welds may well determine the useful operating life of plant or may even jeopardize its safe working. For example, the sharp-edged discontinuity produced as a result of fissuring may act as a stress raiser, which may have serious effects on the behaviour of a pressure vessel.

It is noted that materials falling satisfactorily within the specification limits to which the 18-8-Ti steel is supplied for nitric-acid plant have been found to vary within relatively wide limits with regard to susceptibility to both the '1300°C.' and the '600°-750°C.' effects.

Earlier (unpublished) work, a short review of which is given in this paper, led to the conclusion that both composition and thermal treatment could be important, and this conclusion dictated the lines of the programme of research now reported. It was considered especially important to develop means of minimizing susceptibility to the '1300°C.' effect, since it had already been demonstrated that post-weld heat-treatments at 880°C. would effectively eliminate impairment of corrosion-resistance caused by heating in the 600°-750°C. range.

The present paper comprises three parts, dealing, respectively, with (1) the 600°-750°C. effect, (2) the 1300°C. effect, and (3) 18-8-Ti steels containing 0·06 per cent. carbon (in comparison with the 0·10-0·13 per cent. characteristic of the steels supplied under normal specification, which lays down 0·15 per cent. max.). The acid medium used in the corrosion tests in all three series was an aqueous solution containing 30 wt. per cent. of nitric acid, used at 97°-100°C., a method of test which had previously been found useful as a 'sorting' medium for assessing the relative corrosion-resistance of various batches of 18-8-Ti steel. The specimens were exposed for a total period of 875 hours: they were weighed and the acid solution was renewed at intervals.

Series 1. The influence of titanium, silicon and titanium+silicon content was investigated: carbon was kept constant at 0·10 per cent. Although all the

steels of this group were susceptible to impairment of corrosion-resistance after heating at 600°–750°C., relatively minor variations in titanium content had a marked effect on the degree of deterioration. Optimum Ti: C ratio for maintenance of corrosion-resistance appeared to be about 7·5 : 1, i.e., considerably higher than the 4 : 1 ratio generally accepted as the minimum for stabilization. The effect of silicon, on degree of impairment of corrosion after heating in the 600°–750°C. range, is not significant compared with that of titanium, but it was observed that a steel having high contents of both titanium and silicon showed an intrinsic corrosion-resistance markedly inferior to that of the other steels examined in this group. Corrosion-resistance of 18–8–Ti steel which has been heated in that range can be restored almost completely by heating at 880°C. for two hours.

Series 2. The work described gave clear indication of the susceptibility of 18–8–Ti steels of compositions covered by typical specifications to impairment of corrosion-resistance as a result of heating at 1300°C., e.g., in welding. The resulting fissuring is greatly influenced by the amount of titanium present: specimens containing only 0·4–0·7 per cent. of this element showed relatively slight susceptibility, those containing 0·8–1·3 per cent. proved highly susceptible. While the tests reported did not definitely establish the effect of silicon, the general indication is that it is not a significant factor in relation to the 1300°C. effect. The damage resulting from heating in this higher range cannot be removed by subsequent heat-treatment at 880°C.: in some specimens such treatment grossly aggravated the deterioration. Available data indicate that the 1300°C. damage cannot be remedied by any heat-treatment practicable for welded plant.

Series 3. Resulting from the conclusions recorded above attention was directed to developing a composition which should be immune from deterioration on heating at 1300°C. Examination of various compositions led to the finding that a 0·06 per cent. carbon steel with Ti: C ratio of 5·1 : 1 and normal chromium and nickel contents was much less susceptible to both the 600°–750°C. and the 1300°C. effects than were steels of higher carbon content but otherwise similar chemical composition. Tests on commercial steels of 0·05–0·06 per cent. carbon content confirmed these findings, showing that the improved behaviour may be regarded as representative of 18–8–Ti steels of the compositions examined.

Among the comments made by the authors is the suggestion that the observations with regard to the Ti : C ratio required for elimination of the 600°–750°C. effect indicates that the 'stabilizing' effect of titanium may be more complex than has previously been supposed. Attention is also drawn to the fact that although the 0·06 per cent. carbon 18–8–Ti steels exhibit minimum susceptibility to the 1300°C. effect, the influence of titanium content is still quite significant, in that a steel having 'inadequate' titanium is susceptible to the 600°–750°C. effect, and it is evident that a nominal Ti : C ratio of 4 : 1 is not sufficiently high to provide minimum susceptibility to deterioration of corrosion-resistance after heating in that range. A further feature of importance is the fact that the 'intrinsic' corrosion of the low-carbon steel (i.e., the resistance in the fully softened condition, as commonly supplied for use) is, in general, superior to that of steels of higher carbon content but otherwise similar composition. All the findings of this investigation point to the fact that for welded chemical plant exposed to the severe conditions involved in handling nitric acid the 0·06 per cent. carbon steel, with correct Ti : C ratio, is to be preferred to steel of the 0·10 per cent. carbon content which is now frequently supplied. In many other chemical-plant applications 18–8–Ti steels containing 0·1 per cent. of carbon are, however, entirely satisfactory.

Corrosion by Chlorine: Bibliography

NAT. ASSOCN. CORROSION ENGINEERS: 'A Bibliography of Corrosion by Chlorine.'

N.A.C.E. Publn. 56-2.

Corrosion, 1956, vol. 12, Mar., pp. 141t–8t.

This annotated bibliography, prepared by the Technical Unit Committee T-5A on Corrosion in the Chemical Manufacturing Industry, contains 86 abstracts of papers on corrosion by chlorine.

A condensed subject index is provided, and the material is coded according to the N.A.C.E. abstract filing index.

Galvanic Corrosion of Aluminium in Contact with Various Metals

F. PEARLSTEIN: 'Galvanic Corrosion of Aluminum.'

Metal Finishing, 1956, vol. 54, Apr., pp. 52–7.

Salt-spray tests on bare and on anodized aluminium alloy in contact with various materials indicate the following effects:—

Contact with copper causes rapid and severe corrosion of the aluminium alloy. In contact with steel corrosion of the alloy is considerable, but not so pronounced as when coupled with copper. Anodized aluminium alloy can be used in contact with tin or cadmium plate with little or no adverse effect: the tin itself is unattacked, the cadmium is anodic to the aluminium alloy and is sacrificially corroded. Nickel plating, stainless steel and titanium caused significant attack on the bare alloy.

Nickel-Molybdenum-base Alloy Wire

SOC. AUTOMOTIVE ENGINEERS: 'Alloy Wire, Corrosion- and Heat-Resistant.'

A.M.S. Specification 5786, issued Feb. 1, 1956.

Covering material intended primarily for use as bare wire filler metal for welding similar or dissimilar corrosion- and heat-resisting alloys.

Composition, %: carbon 0·12 max., silicon 1·00 max., manganese 1·00 max., sulphur 0·030 max., phosphorus 0·040 max., chromium 4·00–6·00, cobalt 2·50 max., molybdenum 23·00–26·00, iron 4·00–7·00, vanadium 0·60 max., nickel remainder.

Metallurgical Research in Relation to Nuclear-Power Plant

At the Annual Meeting of the Institute of Metals three papers dealing with metallurgical research in the field of atomic energy were presented for discussion. The scope of the individual contributions is briefly indicated below:

H. K. HARDY: 'Metallurgical Research and Development for Nuclear Power.'

Jnl. Inst. Metals, 1955–56, vol. 84, Mar., pp. 229–38.

The need for development of nuclear power is urged, in relation to anticipated requirements for electricity during the next twenty years. As a means of indicating the scale of effort required, descriptions are given of the Calder Hall type of thermal reactor and the Dounreay experimental fast reactor. Emphasis is laid on the time factor imposed on research and development work by decisions which are reached with regard to construction of power reactors within limited periods: the case of a hypothetical reactor is examined, in which the presumption is a period of five years elapsing from the decision to design, up to the production of power. It is shown that research and development start with a relatively wide range of metallic materials for the respective components, and that these are gradually narrowed down, while the scale of the prototype production and testing is progressively stepped up. In the final section of the paper consideration is given to longer-term investigations which aim at reducing the cost of electricity by providing fuel elements of improved efficiency and longer life. Emphasis is placed throughout on the interdependence of metallurgical research and development of fuel elements and the design and construction of nuclear reactors.

J. G. BALL: 'Metallurgical Research in Nuclear Power Production', *ibid.*, pp. 239–50.

The review is introduced by a condensed discussion of the gradual widening of metallurgical interest arising from continuous developments in the field of nuclear power production: problems involving long-term research or ad-hoc investigation are broadly indicated. Consideration is then given to metals which are of interest to those working in this field: the materials are tabulated in six groups, differentiated according to their applications.

The various types of reactor now being employed are reviewed, with notes on the problems specific to each type, and arising from the review, metallurgical aspects are discussed under the following headings:—irradiation stability of the fuel element, thermal stability of the fuel element, sheathing materials, corrosion (by aqueous and liquid-metal agents, including reference to mass transfer), fabrication (including the need for development of modified methods of extrusion, and the potential value of powder-metallurgy production, consumable arc melting and other procedures), alloying and the physical properties of materials suitable for use in nuclear power plant. Some indication is given of work which is in progress on the various aspects of the subject, and of new fields of investigation which must be explored in order that metallic materials may make the fullest possible contribution to developments in the atomic-energy field.

A. B. MCINTOSH and K. Q. BAGLEY: 'Selection of Canning Materials for Reactors Cooled by Sodium Potassium and Carbon Dioxide', *ibid.*, pp. 251–70.

Research to date has indicated that the basic requirements for a satisfactory canning material are the same for all reactors, but the relative importance of the various factors will vary according to the type of reactor. These requirements are critically discussed. An account is given of the theoretical considerations which are applied to guide choice of materials of construction and of experimental investigations carried out to confirm the suitability of materials selected on theoretical grounds. The paper includes much detailed information on the behaviour of metals and alloys (including nickel, nickel-chromium alloys, and austenitic steels) in conditions which would be involved in canning service. Problems of extraction and/or fabrication at present limit the use of some of the metals which show promise, e.g., beryllium, zirconium, niobium, vanadium, tungsten and molybdenum.

Nickel-Steel Tubing in Oil Wells

NAT. ASSOCN. CORROSION ENGINEERS: 'Field Practices for Controlling Water-Dependent Sweet-Oil-Well Corrosion.'

N.A.C.E. Publn. 56-3, 1956.

Corrosion, 1956, vol. 12, Mar., pp. 149t–53t.

Field practices adopted by nineteen companies in various oil fields in the U.S.A. are recorded, with details of service experience with regard to the success or non-success of the various means used for control of corrosion in water-dependent sweet-oil wells. Methods involving modification of design of equipment, the use of special types of material, and various forms of chemical treatment are critically considered. In the latter connexion a review is made of the service behaviour of plastic-coated tubing, and of special alloy-steel tubing (9, 5 and 3½ per cent. nickel steel types).

Nickel-Alloy Steels in the Mining Industry

See abstract on p. 109.

Nickel-containing Materials in Jewellery

See abstract on p. 99.

Spot-and Seam-Welding of Inconel W

E. F. NIPPES, W. F. SAVAGE and K. L. MOAZED: 'Optimum Spot-and Seam-Welding Conditions for Inconel W.' *Welding Jnl.*, 1956, vol. 35, Mar., pp. 127S–36S.

Since 1939 a sponsored programme of research on the welding of nickel and high-nickel alloys has been in progress at the Rensselaer Polytechnic

Institute. This paper is the latest report in a series which has already covered spot- and seam-welding conditions for Inconel X, seam-welding of Monel, and spot-welding of nickel, Monel and Inconel. Reference to the earlier reports is given in the *bibliography*. (For abstract of the report on welding of Inconel X see *Nickel Bulletin*, 1954, vol. 27, No. 4, pp. 74-5.)

Typical analyses of Inconel W are shown below: its composition is closely similar to that of Inconel X except that the X alloy contains niobium (about 1 per cent.).

The material used was strip cut from sheet of thicknesses varying from 0·010 to 0·062 in. The sheets were supplied in the cold-rolled and solution-treated condition: typical mechanical properties are given in this report.

The criteria for acceptability of welds were those recommended by the Resistance Welding Manufacturers' Association, and used in the investigation on Inconel X (*Nickel Bulletin, loc. cit.*). The tests used included a comprehensive series of destructive and non-destructive methods. Much detailed information is given with regard to welding conditions and testing procedure, and comparisons are made, throughout the report, with data obtained on Inconel X.

Conditions optimum for spot-welding of Inconel W were found to be closely similar to those previously determined for Inconel X, and the mechanical strengths of welds made in the W alloy, under such conditions, were comparable to those found in Inconel X weldments of the same thicknesses. Welds made by the recommended procedures satisfied the R.W.M.A. requirements. Optimum current ranges were in most cases larger for Inconel W than for Inconel X.

It was found that, in spot- and seam-welding of Inconel W, electrode alignment is an important factor, especially when welding thin-gauge material, a feature which had also been observed in the work on Inconel X. It is urged that in welding both alloys careful degreasing and pickling is an essential preparatory step.

Table I

Chemical Composition of Inconel W

C %	Mn %	Fe %	S %	Si %	Cu %	Ni %	Cr %	Al %	Ti %
0·03	0·56	6·48	0·007	0·18	0·08	74·57	14·96	0·71	2·40
0·03	0·52	6·58	0·007	0·29	0·09	74·52	14·79	0·60	2·55

Welding of High-Strength Stainless Steels

J. J. VAGI and D. C. MARTIN: 'Welding of High-Strength Stainless Steels for Elevated-Temperature Use.'
Welding Jnl., 1956, vol. 35, Mar., pp. 137S-44S.

This paper contains a report of work done at the Battelle Memorial Institute, under contract for the U.S. Atomic Energy Commission, on the welding of four types of steel conforming to S.A.E. (A.M.S.) specifications: see table on p. 119.

The types of steel chosen were under consideration for use in construction of pressure vessels to operate, at high pressures, at 800°F. (425°C.). The report contains an account of an extensive study to establish optimum welding procedure for each of the materials, and to determine the effect of heat-treatment on the properties of the welded joints. The results show that the 5616, 5643 and 5528 steels can be satisfactorily welded under conditions of high restraint, using the inert-gas-shielded tungsten-arc process. Full details of procedure are given.

Post-welding heat-treatment proved beneficial: by this means yield strengths of 100,000 p.s.i. (44·5 tons per sq. in.) were obtained in weldments in the three steels mentioned above. It was found that in order to obtain reasonably good elongation values it was necessary to apply a solution annealing treatment as part of the post-welding thermal cycle: temperatures of 1700°-1900°F. (925°-1035°C.) were found suitable, depending, within that range, on the composition of the steel.

The 5735 steel proved to be highly sensitive to hot cracking. Although weldments in $\frac{3}{8}$-in. plate appeared to be satisfactory, attempts to weld this material in heavy plate, highly restrained, were entirely unsuccessful. X-ray diffraction and metallographic studies showed the presence of a low-melting grain-boundary film.

Welding of Stainless Steels: Bibliography

K. JANIS: 'Bibliography on the Welding of Stainless Steels, 1926-1955.'
Welding Research Council Bull., Series No. 25, Mar., 1956; 27 pp.

The *bibliography*, which is unannotated, comprises 1,112 items. An author index is appended.

Production of Sound Stainless Steel Welds of Low Magnetic Permeability

J. L. LANG and C. WRIGHT: 'Permeability and Crack Sensitivity of Stainless Welds.'
Welding Jnl., 1956, vol. 35, Mar., pp. 225-8.

The article describes development of a modified welding electrode for fabricating (by the consumable-electrode inert-gas-shielded arc process) 18-8 chromium-nickel steel Diesel engine crankcases, gear cases, oil pans, deck winches and other components for mine sweepers, in which the requirement was for units as non-magnetic as possible.

Consideration of the relation of ferrite content in the weld metal to (*a*) control of cracking, and (*b*) magnetic permeability, led to the development of a fully

Table I

Composition of High-Strength Stainless Steels used in Welding Experiments*

Type of Steel	C %	Si %	Mn %	Cr %	Ni %	Al %	Fe %	Other Elements %
AMS 5616	0·15	0·5 max.	0·50 max.	13·00	2·00	0·15 max.	Balance	Sn 0·05 max. W 3·00
AMS 5643	0·04	—	—	16·50	3·75	—	Balance	Cu 3·75
AMS 5528	0·07	—	—	17·00	7·00	1·10	Balance	—
AMS 5735	0·045	0·95	1·35	15·52	26·06	0·20	Balance	V 0·32, Ti 1·95

*All values given in weight per cent.

austenitic electrode of modified Type 308, which would ensure permeability values below 2·0 μ and give welds having low susceptibility to hot cracking. The modified composition recommended is carbon 0·115, silicon 0·35, manganese 1·90, chromium 18·41, nickel 10·38, per cent.

Accelerated Test for Determination of Susceptibility to Intergranular Corrosion

J. H. SCOTT: 'Predicting Corrosion-Resistance by Microscopic Examination.'

Metal Progress, 1956, vol. 69, Mar., pp. 79–80, 80B.

The standard boiling-nitric-acid test for determination of susceptibility to intercrystalline corrosion (in austenitic chromium-nickel stainless steels) involves five 48-hour periods, and the complete test cycle may take two to three weeks. In 1953 Streicher proposed an accelerated screening test by means of microscopic examination of specimens electrolytically etched in 10 per cent. oxalic acid (see *A.S.T.M. Bulletin*, Feb., 1953, and abstract in *Nickel Bulletin*, 1953, vol. 26, No. 5, p. 88). According to this test,

(1) if, after etching, any grain is found to be surrounded by a carbide formation the material must be subjected to the standard nitric-acid test,

(2) if carbides are present, but do not surround any grain, the material is classified as a dual structure, and passes without being subjected to the nitric-acid test,

(3) a structure showing no carbide formation is rated as a step structure and also passes without further test.

In the laboratories of Lukens Steel Company, with which the author of this note is associated, the grading obtained by this test on 18-8 standard and extra-low-carbon steels has not proved completely valid as a criterion of behaviour in the standard nitric-acid test: the oxalic-acid test rating tended to reject some material which under nitric-acid test showed satisfactory behaviour. Modified procedure has now been developed, which involves more detailed examination of the structure of samples which have been subjected to the oxalic-acid test. A series of standard photomicrographs has been prepared, based on ratings thus obtained, and the prediction of behaviour from these structures is found to agree closely with resistance to corrosion in the standard nitric-acid test. Typical structures thus graded as 'satisfactory', 'questionable', or 'unsatisfactory' are illustrated, and the series of standard photomicrographs used in routine production control is reproduced, with explanation of the features observed and their significance as a prediction of behaviour.

Determination of Phosphorus in Stainless and Other Steels

W. T. ELWELL and H. N. WILSON: 'The Colorimetric Determination of Phosphorus in Steel and Copper-base Alloys.'

Analyst, 1956, vol. 81, Mar., pp. 136–43; disc., pp. 143–4.

The procedure described is based on the formation of phosphovanadomolybdic acid, which is soluble in *iso*amyl alcohol. The yellow colour formed, which is proportional to the amount of phosphorus present, does not fade, and can be measured in any suitable manner. Study was made, *inter alia*, of the influence of iron, chromium, arsenic, tungsten and copper. The application of the method to a variety of plain, low-alloy and high-alloy (chromium-nickel) steels, also to typical bronze alloys, is recorded, with comparison of the values obtained by this method and certified phosphorus contents of the respective materials.

Determination of Low Carbon Contents in Steels

R. M. COOK and G. E. SPEIGHT: 'The Determination of Small Amounts of Carbon in Steel by Low-Pressure Analysis.'

Analyst, 1956, vol. 81, Mar., pp. 144–52; disc., p. 52.

In the method described, the use of a normal combustion furnace, in conjunction with low-pressure analytical apparatus, permits samples to be analysed with a precision of ±0·0001 per cent. of carbon up to 0·036 per cent. carbon. Deviation is slightly greater with larger amounts of carbon.

The method is adaptable to determination of carbon on a semi-micro basis, when only small weights of sample are available. It is found that with medium- and high-carbon steels analyses may be carried out on samples weighing as little as 0·06 g., with a degree

of accuracy at least equal to that obtained with the normal gravimetric combustion method operated under the best conditions. Full details of apparatus and technique are reported. Test determinations quoted include carbon estimations in carbon steel, austenitic nickel-chromium steels and 80-20 nickel-chromium alloy.

B. BAGSHAWE and R. H. PINDER: 'The Determination of Low Carbon Contents in Steel by Multiple Factor Weight Combustion', *ibid.*, pp. 153-9.

To meet the increasing demand for carbon determinations of third-figure accuracy and reproducibility, the orthodox combustion procedure has been modified to permit combustion of much larger charges than have previously been used. The method is applicable to all classes of low-carbon steels, and is particularly suitable for use in analysis of the extra-low-carbon grades of stainless chromium and high-chromium-nickel steels. Full details are given of the apparatus (with illustrations), and procedure is detailed. It is stated that the general reproducibility of the method, established in the laboratory, has been confirmed by results obtained on a large number of production casts, under service conditions, thus indicating its value as a routine control procedure.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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